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RESEARCH & ENGINEERING DIRECTORATE

ENGINEERING DIVISION

TITLE OF REPORT: ENGINE CORROSION STUDY

FINAL REPORT - PHASE I

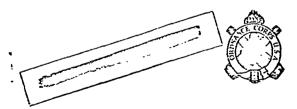
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JAMES DeGROOT

DATE OF REPORT: 29 JUNE 1962

DEPARTMENT OF THE ARMY PROJECT NO. 593-21-062

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SECURITY CLASSIFICATION: UNCLASSIFIED

ENGINE CORROSION STUDY

ORDNANCE TANK AUTOMOTIVE COMMAND

RESEARCH & ENGINEERING DIRECTORATE

ENGINEERING DIVISION

MATERIALS BRANCH

COATINGS & PETROLEUM SECTION

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FINAL REPORT OF PHASE I ENGINE CORROSION STUDY

ON

INSTALLED ENGINES

AS A COMPONENT OF A COMBAT VEHICLE

IN OUTDOOR STORAGE
AT ANNISTON OPDIANCE DEPOT

ANNISTON, ALABAMA

CONDUCTED FROM

JULY 1958 - OCTOBER 1961

PROJECT ENGINEER JAMES DeGROOT OTAC-ORDIC-REM.3

FIELD PROJECT COORDINATOR JAM'S WALLACE
ANNISTON ORDNANCE DEPOT

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ABSTRACT

PURPOSE

To attempt to increase the reprocessing cycle of installed engines in vehicles stored outdoors from the presently used one year to a minimum of three years. Despite improvements in application techniques, corrosion still occurs primarily in the cylinder area in less than one year. By the use of newly developed or improved presently used preservative materials it is possible that maintenance in storage reprocessing operations can be greatly reduced.

RESULTS

VCI oil used in the test proved far superior to the presently used MIL-L-21260 oil after a minimum of three years outdoor storage under actual conditions. Of 24 cylinders (2 test engines) using the VCI oil 17 were corrosion free after three years. The other 7 cylinders developed spotty and not too severe corrosion during the third year of storage.

MIL-L-21260 oil displayed sufficient corrosion on 12 of 24 cylinders to question satisfactory operation of the engine after reassembly without considerable rework and/or salvage. Half of the cylinders showed corrosion in the first year.

CONCLUSIONS

There was no apparent attack from the VCI oil or VCI crystals on non-ferrous or non-metallic components of the engine. The two greatest causes of corroded cylinders of engines are:

- a. Temperature conditions that produce alternate condensation and evaporation of moisture.
 - b. Combustion products producing an acidic environment.

ACKNOWLEDGEMENTS

The assistance, advice, suggestions and contributions of the Annisten Ordnance Depot, Anniston, Alabama were of great value in this program. The interest, ability and cooperation of many of their personnel was both stimulating and inspiring.

Their participation in the many operations so necessary for a program of this scope and magnitude was a united effort. Every activity and individual accomplished their part in a most efficient manner. It was a privilege to work with these many fine people. They deserve a lot of recognition for the accomplishments contained herein.

A special note of thanks to James Wallace,
Packaging Specialist, who did a fine job for the
depot as project coordinator.

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SUMMARY AND CONCLUSIONS

- 1. Very little difference in performance before and after corrosion was noted. After at least three years of outdoor storage only one of 8 test engines would not start. This failure was attributed to improper timing and not corrosion. Minor failures on other engines were not caused by corrosion. It is of interest to note that a penalty in engine performance caused by corrosion is not too significant, based on a 90 minute test run as used in this project. For any future projects of this type at least a 50 hour test run is recommended. Only then will corrosion show the deficiencies worth being concerned about, such as lower compression, increased ring wear and higher cil consumption. Where corrosion is severe enough, ring breakage could occur. Therefore, it is definite that the less corrosion prevalent in the cylinder area, the better for all concerned.
- 2. There was no apparent attack from the VCI oil or VCI crystals on non-ferrous or non-metallic components of the engine.
- VCI oil from the one source used in this test gives much better protection than the presently used MIL-L-21260 preservative vil.
 - 4. The two greatest causes of corroded cylinders of enginesare:
- $\hbox{a. Temperature conditions that produce alternate condensation} \\$ and evaporation of moisture.
- b. Combustion products producing an acidic environment.
 NOTE: See Pages 35 through 38 for further conclusions.

RECOMMENDATIONS

As a result of the most satisfactory performance of VCI oil under actual field conditions, the following recommendations are made:

- a. Set up a fleet test of vehicles in storage with an equal amount of engines processed with VCI cil from at least three sources. Inter-service participation would be desirable. Actual performance under realistic field conditions could be evaluated relative to important characteristics of each VCI oil such as:
- (1) Vapor pressure Too high means short service life of the vapors. Too low will produce inadequate distribution of the vapors.
 - (2) Neutralization of acidic conditions.
 - (3) Toxicity.
 - (4) Compatibility.
 - (5) Solubility.
 - (6) Water displacement and stability.
 - (7) Quality and life of vapor phase and contact preservation.
- b. Qualification people for VCI oil specifications resolve their present differences of opinion and come up with one coordinated document in which all interested sources agree.
- c. VCI cannot be considered practical as an operating oil from many viewpoints, however the possibility of adding 5 to 20% of these oils to the presently used operating oils theoretically offers good potential for a unique way of preservation. This type work could be included in the fleet test recommended.

3

BACKGROUND AND HISTORY:

An OTAC staff study dated 21 June 1956 reveals that engines preserved by current techniques and materials show corrosion in a relatively short time. Areas in the cylinder above piston travel zone were of particular concern. As a result of the staff study improvements in the techniques of application of preservative oils were recognized as necessary and therefore changes in the specification were made. Despite these improvements, corrosion is still possible as a result of human error, shortage of personnel and equipment, infrequent reprocessing or maintenance in storage, inadequate materials and improper use of existing or improved materials.

PURPOSE OF TEST:

This project will attempt to determine the extent of possible improvements attainable by the use of new and/or existing permanent type protective coatings with new and/or improved preservative oils so that inadequacy due to any of the above reasons are either entirely eliminated or greatly reduced.

SCOPE OF PROJECT:

Sufficient laboratory testing has been accomplished to indicate the use of permanent type coatings such as Electrofilm 4856 or phosphate treatment alone on the interior surfaces of the cylinders provides considerably more resistance to corrosion. It is felt that sufficient work is already in process on gymnastication and dehumidified storage. Short range tests such as those that are conducted with laboratory equipment like humidity and salt spray cabinets or preservative oils applied to panels and disassembled engine cylinders have provided guide lines for more extensive testing. In these short range tests, the advantages of much quicker results are recognized, however, the question of simulated conditions has to be taken into The question always arises, would the same results be achieved under actual co ditions where products of combustion are prevalent as the cylinder would be an integral part of the engine with the sealed chamber. Also exposure to the nature elements is far different than laboratory equipment not to mention the variations that can occur even between exposure on spare engines and those installed as a component of a vehicle.

Test engines No's 1, 2, 3 & 4 were rebuilt by the Experimental Division, Detroit Arsenal. In order to assure corrosion free engines, cylinders, pistons, rings, intake valves and exhaust valves were either reworked or replaced as deemed necessary. The same was accomplished on test engines No's 5, 6, 7 & 8 by Anniston Ordnance Depot. All eight rebuilt test engines were then installed into

vehicles and run 100 miles on the dirt test track at Anniston Ordnance Depot. All test engines were then processed in accordance with the materials outlined in the following chart applicable to each engine. Application techniques as outlined in MIL-STD-53% were carefully adhered to with the exception of the VCI plugs which are not covered in such publication.

Test plans call for a boroscope examination of each cylinder after the first and second year of storage. After the third year of storage test engines will be removed from the vehicle, completely disassembled and carefully evaluated. The purpose and objective of this project to evaluate various combinations of preservative oils, volatile corrosion inhibitor plugs, phosphate and electrofilm finishes will be fulfilled with the hope that maintenance care and preservation expenditures can be greatly reduced by definite recommendations of the best preservative materials or combinations thereof. Completion date estimated to be October 1961.

PHASE II

Phase I involved 8 test engines installed into 8 combat vehicles. Actual conditions of vehicle operation, processing and storage were simulated in Phase I, however considerable expense was necessary for such method of evaluation. Therefore limited funds restricted the evaluation of only a few of the most promising preservative materials under such test conditions. Other services have conducted field tests with considerable success on engines exposed to the elements in wooden boxes, thereby simulating to a certain degree protection afforded to installed engines in equipment such as aircraft tanks, trucks, etc. Therefore Phase II was implemented in April 1959 to include several more newly developed or improved currently used preservative materials utilizing 18 test engines and 9 preservative materials. (2 engines for each material). Higher authority did not approve the loan of 18 vehicles for 3 years, the duration of the test. Therefore engines were to be placed under the protection of reusable exterior wood containers after rebuild. 10 hour run on a dynamometer and processing. Two annual partial teardown evaluations have been accomplished. Third and final complete teardown evaluation will be completed in February 1963.

PHASE III

Sufficient information and data have been ascertained from Phase I & II to warrant a third phase. When Phase I of this study started in 1958 only one VCI oil was available. There are now at least three with improvements in contact inhibitors, vapor space inhibitors and acid neutralizers. Only recently a specification was issued. Also in the last four years improvements have been attained in processing techniques. Past difficulties in engine

preservation were due in part to this factor. Therefore it is deemed advisable to evaluate the standard preservative oil with improved application techniques and still maintain a control material. Plans are now finalized to utilize 12 more boxed engines using the same rebuild operations and storage conditions as Phase II. Paterials to be tested will include at least four VCI preservative oils, one special spark plug type container of VCI crystals and one standard NIL-L-21260 oil with the latest developed application techniques. Plans now call for this phase to be implemented in the early fall of 1962. Areas of consideration for future work include diesel engines, multi-fuel engines and the possibility of adding varying amounts of VCI oil to the standard preservative operational oil.

GENERAL SPECIFICATIONS OF TEST ENGINES NO'S. 1,3,5,6,7 & 8
12 Cylinder, V type, Gasoline.

Coolant - Air

Cycle - 4 Stroke.

Bore - 5.75 in.

Stroke - 5.75 in.

Displacement - 1791.94 cu.in.

Compression Ratio - 6.5:1

Gross h.p. - 810 @ 2800 RPM

Max. Torque - 1580 1b.ft. @ 2200 RPM

Valve Arrangement - Overhead Camshaft - 2 valves per cylinder.

Max. BMEP - 132 psi @ 2200 RPM

Max. Engine Air Demand - 1280 cfm @ 2800 RPM

DIMENSIONS

Length - 73.92 in.

Width - 59.82 in,

Height - 40.65 in.

Weight (Dry) - 2605 lbs.

Oil Capacity - 18 gal.

NOTES - Test Engines No's 1, 3, 5 & 6 Fuel Injection Type.

" " 7 & 8 Carburetor Type.

Cylinders are individually replaceable units, arranged in 2 banks numbered 1 to 6 on the right and 1 to 6 on the left when viewed from the accessory end or front. GENERAL SPECIFICATIONS OF TEST ENGINES NO's 2 E

6 Cylinder, Horizontal, Opposed, Supercharged, Carbureted.

Coolant - Air

Cycle - 4 Strake

Fuel - Gasoline - FIL-G-3056

Bore - 5.75 in.

Stroke - 5.75 in.

Displacement - 895.9 cu.in.

Compression Ratio - 5.5:1

Gross h.p. - 500 @ 2800 RPH

Max. Torque - 955 lb.ft. @ 2200

Valve Arrangement - Overhead camshaft, 2 valves per cylinder.

Max. BMEP - 161 psi @ 2400 RPM

Max. Engine Air Demand - 845 cfm @ 2800 RPM

DIMENSIONS

Length - 47.43 in.

Width - 51.56 in. Height - 34.81 in.

Weight (Dry) - 1861 lbs.

Oil Capacity - 11 gal.

NOTES - Cylinders are individually replaceable units, arranged in two banks, numbered 1, 3 & 5 on the right and 2, 4 & 6 on the left when viewed from the accessory end or front.

PROCESSING PROCEDURES

Test engines #1 thru 6 were processed in the following manner before going into storage.

A container with two compartments, one filled with oil, Specification MIL-L-644, the other with fuel, Specification MIL-G-5572 shall be used. Fuel line from the container shall be connected to the vehicle fuel line at an accessible point which is most distant from the engine. For injection type engine, the injector fuel return line shall be disconnected at quick disconnect coupling and the female quick disconnect coupling on the line from the container shall be connected to the male quick disconnect fitting. For carburetor type engines, the fuel intake line shall be disconnected from the fuel tank side of engine driven fuel pump and the female quick disconnect coupling on the line from the container shall be connected to the male quick disconnect fitting. Container regulator valve shall be turned to the FUEL position. Engine shall be started and operated at a minimum speed for one minute, then accelerated to three-fourths speed without load. Container regulator valve shall be turned to OIL position. At the instant engine begins to misfire, the ignition or magneto switches shall be turned to the OFF position. Fuel line of the container shall be disconnected and vehicle fuel line reconnected. Engine shall be cooled to 100°F or below measured at spark plug gasket surfaces of all cylinders. Spark plugs shall be removed and handled carefully to avoid damage to electrodes and threads. Two ounces of preservative oil, as indicated on each engine graph sheet were atomized sprayed into each cylinder through the spark plug opening while engine is being cranked with starting motor. Two additional ounces of the same test oils were then atomized sprayed into each cylinder without cranking. Threaded ends of spark plugs shall be reinstalled and engine not to be cranked anymore.

Test engines \$7 and 8 had only the left bank of cylinders atonized sprayed through the spark plug openings with the designated test oil. Plastic plug containers each containing 4 grams of VCI crystals (1 to a cylinder) were inserted into the spark plug opening. Dry compressed air was then applied to the outer end of the plug so as to force the VCI crystals into the combustion area of the cylinder. Plastic plugs were then removed and spark plugs reinstalled.

MOTE - Before any processing as noted above is accomplished engine crankcases are filled to operating level with preservative oil MIL-L-21260, grade determined by vehicle and operating concitions.

STAGES OF CORROSION FROM MIL-STD-634(ORD) COMBAT VEHICLES, INSPECTION, CARE AND PRESERVATION DURING STORAGE OF

Stages of Corrosion	Identification Stage Description
Stage 1	Discoloration, staining. No direct visual evidence of pitting, etching or other surface damage.
Stage 2	Loose rust, black or white corrosion accompanied by minor etching and pitting of surface affected. No scale, or tight rust.
Stage 3	Rust, black or white corrosion accompanied singly or in combination with etching, pitting or more extensive surface damage. Loose or granular condition.
Stage 4	Rust, black or white corrosion progressed to the point where fit, wear function or life of the item has been affected. Powdered or scaly condition, with pits or irregular areas of raterial removed from surface of item.

VISIT OF TASK GROUP

On 11 and 12 October 1961 the service wide Task Group on Preservatives and Preservation visited Anniston Ordnance Depot. This is a group of about 20 individuals, scientists, engineers, technicians and specialists representing the Army, Navy, Air Force, Marine Corps and Department of Defense primarily interested in all the technical aspects of preservation. Quarterly meetings are held usually at some installation where some program or activity is of sufficient interest to all. This project had been a topic of discussion at their previous meetings.

The Ordnance Corps was honored by the group's decision to hold their 1961 fall meeting at the Anniston Ordnance Depot to view first hand this Ordnance Tank-Automotive Command Engine Corrosion Study. They held their regular business meeting the first day 11 October 1961. The second day 12 October 1961 the entire group plus four more service representatives participated in the third annual evaluation of the partially disassembled 8 test engines. Formal and informal discussions were held before, during and after the actual inspection of the engines and various components. Comments, suggestions and constructive criticism offered by various members of the group were most helpful especially for future concepts. The Task Group is under the capable chairmanship of David Bootzin, ORDBC-9320-DB. Rock Island Arsenal Laboratories while the duties of Secretary are most efficiently handled by Gerald Reinsmith, ORDOW-TB, Ordnance Weapons Command, Rock Island, Illinois. Everyone agreed that Anniston Ordnance Depot was the perfect host for the two day conference.

CODE FOR ABBREVIATIONS USED FOR DIAGRAM SHEETS OF ENGINES AND CYLINDERS WHERE LACK OF SPACE RECESSITATES SUCH

Stage (referring to degree of corrosion) - #

Corrosion - Corr

Cylinder - Cyl

Entire - Ent

Wide - W

Long - L

GODE FOR NUMBERS AND LETTERS WITHIN CIRCLES ON DIAGRAMS OF CYLINDERS

E - Electrofilm Coated Cylinders.

W - West Coast Application of Electrofilm (Parent Company)

D - Detroit Application of Electrofilm (Licensee)

1L-6L - Number of Cylinder L - Indicates Left Bank.

1R-6R - Number of Cylinder R - Indicates Right Bank.

P - Phosphate Coated Cylinders.

B - Bare Cylinders - No Permanent Type Coating.

EXPLANATORY NOTES FOR C1. IN ER REMOVAL

Some cylinders were removed for the following reasons, during the first and second annual evaluations.

- a. To compare the naked eye visual inspection to results obtained by the boroscope.
- b. To verify condition of the cylinder, especially where any difference of opinion exists between three individuals after using the boroscope.
- c. Some cylinders have the pistons at the top of the compression stroke, hence nothing can be seen with the boroscope.

INFORMATION ON ANNUAL EVALUATIONS

The next 33 pages (13 thru 40) in words and diagrams show results of the three an mal evaluations. The first and second year evaluations were confired to partial disassembly of the test engines. The third year and final evaluation was a complete disassembly of the test engines, inspection of components, reassembly and brief test run for efficiency of operation. Each evaluation is divided into three areas of information namely: (a) Seneral Summary, (b) Detailed Summary, (c) Graphical Summary.

First Annual Evaluation - Pages 13 thru 22

Second " " - " 23 " 34

Third " " - " 35 " 46

The general and ϵ illed summary of the third annual evaluation (Pages 35 % u.s) naturally supplements the brief summary and corrected shown on Page 1.

GENERAL SUMMARY OF FIRST ANNUAL EVALUATION

Every cylinder in each engine was boroscope inspected by three individuals. Observations were discussed periodically. One cylinder from each bank of cylinders of all engines was removed for inspection with the naked eye, so comparison of results could be made with boroscope findings.

All engines processed with MIL-1-21260, Grade 2 the present engine preservative oil, displayed from 1 to 7 corroded cylinders most of which had reached the stage 3 type of corrosion.

No difference could be ascertained in protective qualities between low and high limit MIL-L-21260 oils.

The use of permanent type coatings on the piston travel area such as phosphate or electrofilm prior to processing with the standard preservative oil offers little added protection, when compared to the bare cylinders with the same oil. It was noted that most of the coating material had been removed on the 100 mile test track run.

Volatile Corrosion Inhibitors either in oil or crystal form performed remarkably well. The four AV-1790 engines processed with VCI materials produced 48 corrosion free cylinders, after 14 months outdoor storage.

VCI crystals when blown in the cylinders have a tendency to build up especially at the top of the cylinder. This condition would prove troublesome when considering the minute openings of injector nozzles of fuel injection and diesel engines. This condition was caused by the use of air pressure to the VCI crystal plugs after they had been inserted in the spark plug openings in accordance with the supplier's instructions. The omittance of the air pressure for blowing the crystals in the cylinder would rectify this condition. It would then be interesting to see if sufficient vapors would be released into the cylinder area to perform as well. This will be checked in another phase of the project.

The partial disassembly only permitted a partial visual inspection of the valves, rings, pistons and other components. Past experience reveals the cylinder interior walls as the most susceptible to corrosion, hence the emphasis on this area at this time.

DETAILED SUMMARY OF FIRST ANNUAL EVALUATION

Engine #1 - Low limit MIL-L-21260 Grade 2

5 of 12 cylinders remained corrosion free for one year

7 of 12 cylinders exhibited stage 3 corrosion in areas ranging from 1/2" to 1" wide and from 1800 - 3600 of the circumference of the piston travel area.

Engine #2 - High limit MIL-L-21260 Grade 2

4 of 5 cylinders remained corrosion free for one year

1 of 6 cylinders showed stage 3 corrosion, 1" wide for 300°

of the circumference of the piston travel area.

1 of 5 cylinders showed stage 3 corrosion 1/8" wide and 1" long.

Engine #3 - High limit MIL-L-21260 Grade 2

7 of 12 cylinders remained corrosion free for one year

2 of 12 cylinders displayed stage 2 corrosion for an area

of 1" x 4" in piston travel area.

1 of 12 cylinders displayed stage 3 corrosion in various spots

over the entire piston travel area.

2 of 12 cylinders showed stage 3 corrosion for 1"-1-1/2" wide from 270°-360° of the circumference of the piston travel area.

Engine #4 - Low limit MIL-L-21260 Grade 2

5 of 6 cylinders remained corrosion free

1 of 6 cylinders exhibited stage 3 corrosion of 1" wide for 3000 of the circumference of the piston travel area.

Engine #5 - VCI 0il.

All 12 cylinders free of corrosion.

Engine #6 - VCI 0il.

All 12 cylinders free of corrosion.

Engine #7 - Left Bank of 6 cylinders VCI plugs plus low limit

MIL-L-21260 Oil, Grade. Right Bank - VCI plugs only, no oil through spark plug openings.

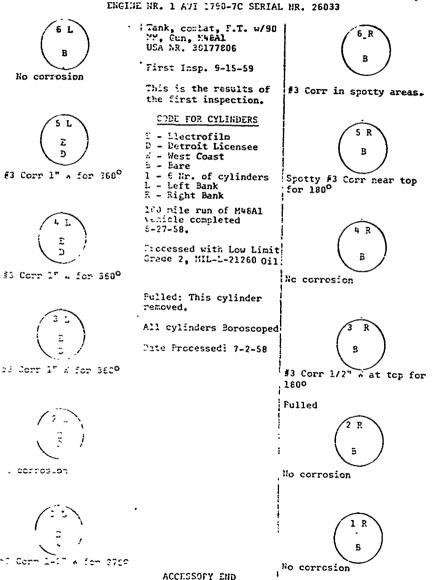
All 12 cylinders remained corrosion free.

Engine #8 - Same as #7

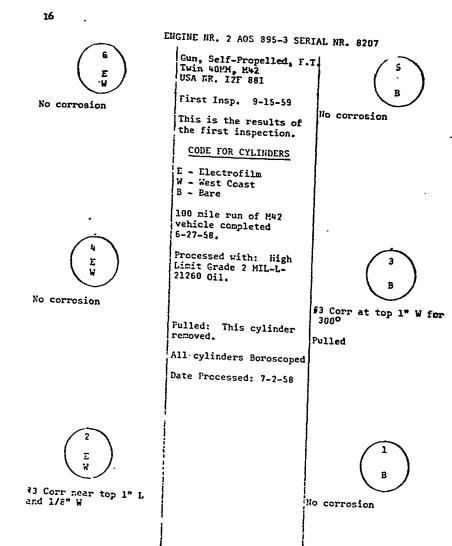
All 12 cylinders remained corrosion free.

NOTE - Detailed graphical sheets on each engine and each cylinder follow.

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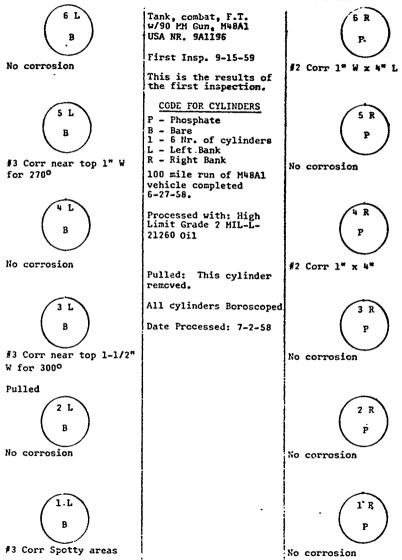
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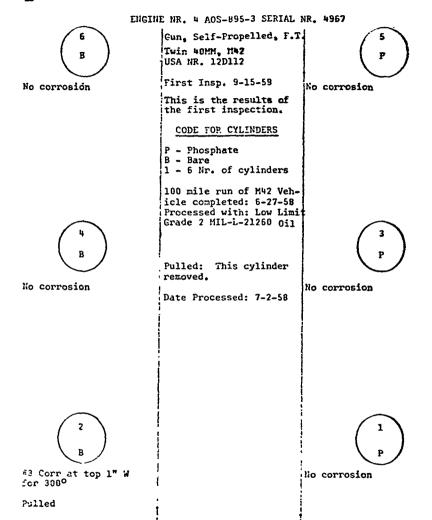
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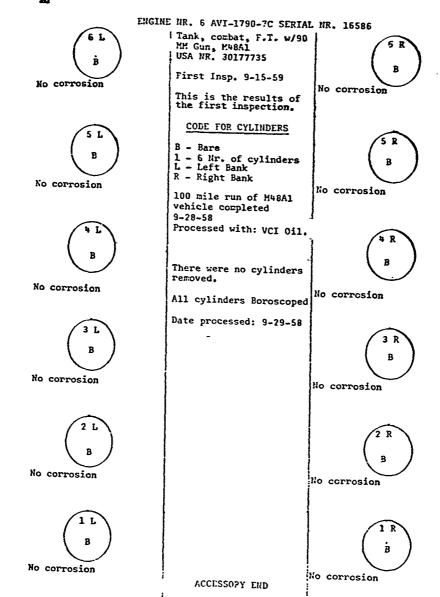
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ENGINE ER. 5 AVI-1790-7C SERIAL NR. 21040 Tank, combat, F. T. w/90 HM Gun, M48AL 61. USA NR. 30177800 First Insp. 9-15-59 No corrosion No sorrosion This is the results of the first inspection. CODE FOR CYLINDERS B - Bare 1 - 6 Nr. of cylinders L - Left Bank R - Right Bank No corresion No corresion 100 mile run of M48Al vehicle completed 9-28-58 Processed with: VCI 0il All cylinders Boroscoped No corresion No corresion Date Processed: 9-29-58 No corrosion No corrosion No corrosion No corrosion Pulled Pulled No corrosion No corrosion ACCESSORY END

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ENGINE NR. 7 AV-1790B SERIAL NR. 18620 Tank, combat, F.T. w/90 MH Gun, M48Al USA NR. 30173160 First Insp. 9-15-59 No corrosion No corrosion This is the results of the first inspection. CODE FOR CYLINDERS B - Bare 1 - 6 Wr. of cylinders L - Left Bank R - Right Bank No corrosion No corresion Pulled 100 mile run of M48Al vehicle completed 9-28-58. 1 - 6 Left Bank cylinders processed with: Low Limit Grade 2 MIL-L-21260 plus V.C.I. Plugs No corrosion in spark plug openings. No corresion Pulled: This cylinder removed. All cylinders Boroscoped Date processed: 9-29-58 No corrosion No corresion 2 L No corresion No corrosion

ACCESSORY END

No corresion

No corrosion

No corresion

ENGINE NR. 8 AV-1790B SERIAL NR. 51108 Tank, Combat, F.T. w/90 MM Gun, M48A1 USA NR. 9A1195 First Insp. 9-15-59 No corrosion No corresion This is the results of the first inspection. Code For Cylinders B - Bare L - Left Bank R - Right Bank 1 - 6 Nr. of cylinders No corresion 100 mile run of M48Al No corresion vehicle completed Pulled 9-29-58 1 - 6 Left Bank cylinder processed with: Low Limit Grade 2 MIL-L-21260 plus V.C.I. Plugs in Spark Plug openings. No corrosion No corresion 1 - 6 Right Bank cylinders processed with: VCI Plugs only, no oil thru spark plug openings. Pulled: This cylinder removed. All cylinders Boroscoped No corresion No corresion Date processed: 9-29-58 2 R No corresion No corresion

ACCESSORY END

No corrosion

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GENERAL SUMMARY OF SECOLD ANHUAL EVALUATION

Every cylinder in each engine was boroscope inspected by three individuals. Individual cylinders in some cases were completely removed for maked eye visual inspection, where any doubt or difference of opinion existed on the boroscope examination.

All engines processed with MIL-L-21260 preservative cila displayed at least 50% of the cylinders corroded, most of which had reached the stage 3 type.

With the MIL-L-21260 processed engines, cylinders that had displayed correction after the first ennual inspection; had increased in severity and area affected. Also some cylinders not corroded after the first year were now affected.

The difference between the preservative qualities of low limit and high limit MIL-L-21260 oils was noticeable, indicating better results with material considered in the higher bracket of qualification.

The use of permanent type coatings such as phosphate or electrofilm on the cylinder walls prior to processing with the standard preservative oil (MIL-L-21260) offers little added protection, when compared to the bare uncoated cylinders, processed with the same oil. Observation indicated that most of such type coatings had been removed on the 100 mile test run before the original processing.

Practically all interior cylinder surfaces appeared quite dry with little or no evidence that oil had been atomized through the spark plug openings. This indicates the drain off characteristics of the oils used especially on vertical surfaces over a long period of time.

VCI oil (Eng #5 & 6)appeared best as no corrosion was found on any of the 24 cylinders after two years' storage. The fantastic part is that this is the second time in two years that the engines have been removed from the vehicles and set around for days with one spark plug removed from each cylinder. Apparently the contact and volatile protection was not too adversely affected by the excessive handling of the engines necessary to accomplish the evaluations.

VCI crystels (Eng. \$7 & 8) in combination with MIL-L-21260 oil through the spark plug openings displayed only 3 of 12 cylinders with corrosion which had developed during the second year of storage and was confined to small areas. It was noted that the crystals were prevalent on the interior surfaces of the cylinder and when oil had been atomized through the spark plug openings there was a tendency of build-up in some areas of the two raterials. In fact, through a boroscope these areas had the appearance of corrosion.

CENERAL SUMMARY OF SECOND ANNUAL EVALUATION

Only when the cylinders were removed for visual inspection, was it discovered that corrosion did not exist in these areas. This could be another potential trouble area when considering the minute openings of injector nozzles of fuel injection and diesel engines.

VCI crystals without MIL-L-21260 oil atomized through the spark plug openings likewise produced only 3 of 12 cylinders with corrosion developed during the second year of storage and again this corrosion was only in small areas.

DETAILED SUMMARY OF SECOND ANNUAL EVALUATION

Engine #1 - Low limit MIL-L-21260 Grade 2

2 of 12 cylinders remained corrosion free for two years

2 of 17 cylinders exhibited stage 3 corrosion on the entire piston travel area.

1 of 12 cylinders had spotty stage 1 and 2 corrosion on the entire piston travel area.

4 of 12 cylinders displayed stage 3 corrosion in areas ranging from 1/2" to 1" wide and from 1800-3600 of the circumference of the piston travel area.

3 of 12 cylinders displayed small areas of stage 1 and 2 corrosion ranging from 1/4" to 1" wide up to 60 of the circumference of the piston travel area.

Engine #2 - High limit MIL-L-21260 Grade 2

3 of 6 cylinders remained corrosion free for two years

3 of 6 cylinders developed stage 3 corrosion in streaks and bands from 60°-300° of the circumference of the piston travel area and from 1/8" to 1" wide.

Engine #3 - High limit MIL-L-21260 Grade 2

5 of 12 cylinders remained corrosion free for two years I of 12 cylinders developed spotty stage 3 corrosion over entire

piston travel area. 1 of 12 cylinders developed stage 1 corrosion over top half of

piston travel area. 3 of 12 cylinders, no noticeable change from first annual evalu-

ation.

1 of 12 cylinders, stage 3 corrosion over top half of piston travel area.

1 of 12 cylinders displayed spotty stage 1 corrosion over entire piston travel area.

Engine f4 - Low limit MIL-L-21260 Grade 2

2 of 8 cylinders remained corrosion free for two years

3 of 6 cylinders developed stage 3 corrosion, 2" wide band for 360° of the circumference of the piston travel area.

1 of 6 cylinders, no change from first evaluation

Engine £5 -' VCI Cil.

All 12 cylinuers retained free of corresion for two years

Engine #5 - VCI Oil.

All 12 cylinders remained free of corresion for two years

DETAILED SUMMARY OF SECOND ANNUAL EVALUATION

Engine #7 - Left bank, VCI plugs plus low limit MIL-L-21260 oil Right bank, VCI plugs only

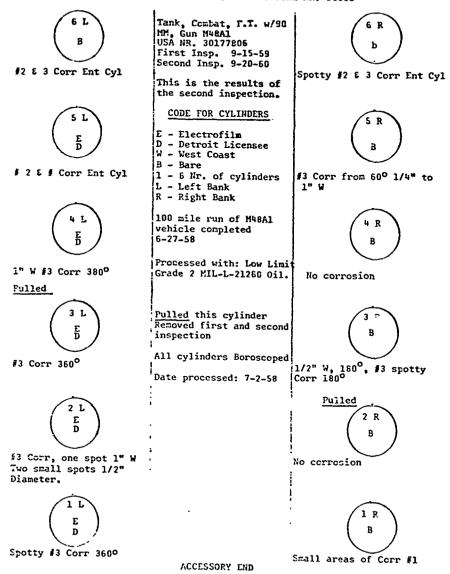
11 of 12 cylinders remained corrosion free for two years 1 of 12 cylinders developed stage 3 corrosion, 1" wide band for 90° of circumference of piston travel area.

Engine #8 - Left bank, VCI plugs plus low limit MIL-L-21260 oil Right bank VCI plugs only

7 of 12 cylinders remained corrosion free for two years 5 of 12 cylinders developed strips and spots of stage 2 corrosion from 1/4" to 2" wide on 60°-160° of the circumference of the piston travel area.

ENGINE NR. 1 AVI-1790-7C SERIAL NR. 26033

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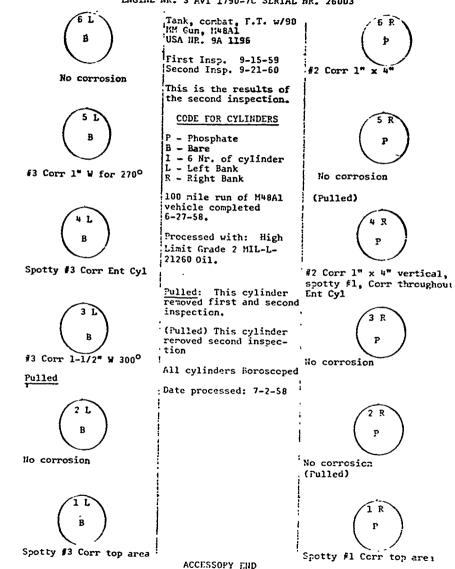
ENGINE NR. 2 AOS 895-3 SERIAL NR. 8207 Gun, Self-Propelled, F.T. Twin 40PM M42 'USA NR. 12F881 First Insp. 9-15-59 Second Insp. 9-20-60 No corrosion No corresion This is the results of the second inspection. CODE FOR CYLINDERS E - Electrofilm W - West Coast B - Bare 100 mile run of M42 vehicle completed 6-27-58. Processed with: High Limit Grade 2 MIL-L-21260 7-2-58. No corresion Same as first inspection plus 1" strip of #2 Corr extended from top of piston travel to bottom of Cyl Pulled: This cylinder removed first and Pulled second inspection. All cylinders Borcscoped Date processed: 7-2-58 #3 Corr, near top 1" L Several spotty streaks,#3
Corr 600 and above ring travel

ACCESSORY END

ENGINE NR. 3 AVI 1790-7C SERIAL NR. 26003

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ENGINE NR. 4 AOS 695-3 SERIAL NR. 4967 Gun, Self-Fropelled, F.T. Twin 40MM M42, USA NR. 12D112

professoration from a first to state the probability of the confidence of the confid

#3 Corr spotty for 3600 top half Cyl (Pulled)

First Insp. 9-15-59 Second Insp. 9-21-60 This is the results of the second inspection.

CODE FOR CYLINDERS

1 - 6 Nr. of cylinders 100 mile run of M42

No corrosion (Pulled)

vehicle completed 6-27-58 Processed with: Low Limit Grade 2 MIL-L-21260 Oil.

P - Phosphate B - Bare

#3 Corr 360° 2" W top of ring travel area.

Pulled: This cylinder removed first and second

(Pulled) inspection ion.

#3 Corr 2" W 3200 top of ring travel area.

(Pulled) This cylinder removed second inspect-Date processed: 7-2-58

Same as first inspection with increased Corr.

No corrosion

Pulled

(Pulled)

(Pulled)

ACCESSORY END

ENGINE NR. 5 AVI-1790-7C SERIAL NR. 21040 Tank, combat, F.T. w/98 MM Gun, M48Al USA NR. 30177800 First Insp. 9-15-59 No corresion Second Insp. 9-20-60 No corrosion This is the results of the second inspection. 5 L CODE FOR CYLINDERS B - Bare 1 - 6 Nr. of cylinders L - Left Bank No corrosion R - Right Bank No corresion 100 mile run of M48Al vehicle completed 9-28-58. Processed with VCI 0il. No corrosion No corresion Pulled: This cylinder removed first and second inspection. 3 L All cylinders Boroscoped Date processed: 9-29-58 No corresion No corresion No corrosion No corrosion Pulled Pulled 1 R

ACCESSORY END

No corresion

No corresion

ENGINE NR. 6 AVI-1790-7C SERIAL NR. 16586

LHOINE MR. 6 AVI-1790-7C SERIAL NR. 16586			
No corrosion	Tank, combat, F.T. w/90 MM Gun, M48A1 USA NR. 30177735 First Insp. 9-15-59 Second Insp. 9-20-60	6 R B	
5 L B	This is the results of the second inspection. CODE FOR CYLINDERS B - Bare 1 - 6 Nr. of cylinders	5 R	
No corrosion	L - Left Bank R - Right Bank 100 mile run of Ku8Al vehicle completed 9-28-58	No Corrosion	
No corrosion	There were no cylinders removed.	No corrosion	
$\begin{pmatrix} 3 & \Gamma \\ \end{pmatrix}$	All cylinders Boroscoped Date Processed: 9-29-58	3 R B	
No corrosion		No corrosion	
B B		(2 R B	
No corrosion		No corrosion	
(B		(1 R B	
No corrosion		No corrosion	

ACCESSORY END

ENGINE NR. 7 AV-1790-3 SERIAL NR. 16620 Tank, combat, F.T. u/90 MM Gun, M48AI USA NR. 30173160 First Insp. 9-15-59 Second Insp. 9-20-60 No corresion No corresion This is the results of the second inspection. CODE FOR CYLINDERS B - Bare 1 - 6 Nr. of cylinders L - Left Bank No corrosion R - Right Bank No corresion Pulled 100 Mile run of M48Al vehicle completed 9-28-58 1 - 6 Left Bank Cylinders processed with Low No corresion Limit Grade 2, MIL-L-No corresion 21260 plus V.C.I. plugs (Pulled) in spark plug openings. 1 - 6 Right Bank Cylind-3 L ers. No oil thru spark 3 R plug openings, only VCI B plugs. В Pulled: This cylinder removed first and second No corrosion No corresion inspection. (Pulled) (Pulled) These cylinders removed second inspection. All cylinders Boroscoped Date processed: 9-29-58 No corresion No cerrosion No corresion #3 Corr 1200 1"x3" ¥ ACCESSORY END

BARANAN BUTAN KANDAN KANDAN KANDAN KANDAN KANDAN BARAN KANDAN KANDAN KANDAN KANDAN KANDAN KANDAN KANDAN KANDAN

No corrosion

ACCESSORY END

No corresion

(Pulled)

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- VCI 0il (Eng 566) proved best by keeping 17 of 24 cylinders corrosion free for three years. The other seven cylinders which developed corrosion during the third year of storage were spotty and not near as severe as the other engines.
- VCI crystals (Eng #7 & 8) alone or with MIL-1 '60 proved second best with 3 of 24 cylinders corrosion frethe 21 cylinders developed corrosion duritorially all the corrosion was suffined to spots or bands 1/2" 1" wide, 90° 360° of the circumference of the piston travel area.
- MIL-L-21260 oil displayed sufficient corrosion on half the cylinders to question satisfactory operation of the engine after reassembly without considerable rework and/or salvage.
- There was a more noticeable difference in the performance of the two sources of MIL-L-21260 oil. One source considered borcerline insofar as meeting the requirements of the specification did not perform as well as another source material that our qualification people regard as far above the minimum specification requirements. In the test these materials were designated as low limit and high limit accordingly.
- The combination of a phosphate treatment plus MIL-L-21260 oil performed slightly better than the same oil on the bare cylinders, however, not sufficiently superior to warrant the time, cost and labor of phosphate coating each cylinder.
- The use of electrofilm (combination lead, tin and graphite) with oil did no better han the same oil on bare cylinders. Also no difference was noted between the coating as applied by the parent company or one of it's licensees.
- All cylinders were both boroscope inspected then removed for actual visual inspection. Cenerally speaking the comparison revealed the extent and degree of corrosion is most difficult to ascertain strictly by boroscope readings. Therefore, the findings on the detailed sheets for the third evaluation show the actual condition as determined by visual inspection after removal of the cylinders from the engine. Upon complete teardown, other components were checked for corrosion and/or deterioration. Engines were then reassembled, tested on a power pack test stand for efficiency of operation with particular emphasis on performance relating to the following characteristics and components.

Oil Pressure
Roise
Slow By
Stall Test (RPM
Compression Readings
of Each Cylinder)

Yagnetos Carburctors Ignition Harness Generator Starter Fuel Filter Oil Filter Element Engine #1 - Low Limit MIL-L-21260, Crade 2 011.

- 1 of 12 cylinders remained corrosion free for three years.
- 2 of 12 cylinders exhibited Stage 3 corrosion for the entire piston travel area.
- 1 of 12 cylinders exhibited Stage 2 & 3 corrosion spots over the entire piston travel area.
- 1 of 12 cylinders displayed Stage 3 corrosion for 2/3 of the
- entire piston travel area.

 7 of 12 cylinders exhibited Stage 2 & 3 corrosion spots and bands for the entire circumference from 1" 2" wide.

Upon reassembly and testing on a power pack test stand for efficiency of operation, the following deficiencies were noted.

- a) 0il pressure was 45 P.S.I. at 2800 RFM, acceptable is 60 - 70 P.S.I. Assumption is this was caused by worm bearings and not storage deficiency.
- b) Generator showed no change, probably caused by previous disassembly and/or workmanship and not deterioration.
- c) Governor was unserviceable. Not due to storage.

Engine #2 - High Limit MIL-L-21250, Grade 2 011.

- 4 of 6 cylinders displayed Stage 2 \$ 3 corrosion on entire
 piston travel area.
 2 of 6 cylinders displayed Stage 2 \$ 3 corrosion spots over
- entire piston travel area.
 Upon reassembly and testing on a power pack test stand for

efficiency of operation, no deficiencies were noted.

Engine #3 - High Limit MIL-L-21260, Grade 2 0il.

2 of 17 Cylinders showed no corrosion after three years.

and the second of the control of th

- 1 of 12 cylinders displayed Stage 2 & 3 corrosion on the entire
- piston travel area.
 4 of 12 cylinders showed Stage 2 corrosion spots on the entire
- piston travel area.
- 3 of 12 cylinders displayed stage 3 corrosion bands 1-1/2" 2" wide for 3000-3600 of the circumference of the piston travel area.
- 1 of 17 cylinders displayed Stage 1 corrosion for top half of piston travel area.

Upon reasonably and testing on a power pack test stand for efficiency of operation, engine would not start due to improper timing.

Engine # 4 - Low Limit NIL-L-21260, Grade 2 0il.

All 6 cylinders corroded.

1 of 6 cylinders, Stage 3 corrosion over entire piston travel area. 1 of 6 cylinders, Stage 2 & 3 corrosion spots over entire riston

travel area.

4 of 6 cylinders, Stage 3 corrosion bands 1-1/2"-2" wide for 3000-3600 circumference of piston travel area.

Upon reassembly and testing on a power pack test stand, the only deficiency was the ignition harness which was damaged due to the handling in the three teardowns.

Engine #5 - VCI 0il.

3 of 12 cylinders for incd corrosion free for 3 years. 3 of 12 cylinders, Stabe 2 corrosion spots on entire piston

travel area.

1 of 12 cylinders, Stage 2 corrosion band 1/8" wide for 180° of circumference of piston travel area.

Upon reassembly and testing on a power pack test stand, no operating deficiencies were found.

Engine #6 - VCI Oil.

= 6.1 1/ cylinders received corrosion free for three years.

2 of 12 cylinders Stage 2 corrosion spct 1/2"-2-1/2" wide by 2-1/2" long.

1 of 12 cylinders Stage 1 & 2 corresion spots on lower half of piston travel area.

Upon reassembly and testing on a power pack test stand no operating deficiencies were noted.

Engine \$7 - Left Bank - VCI plugs plus Low Limit MIL-L-21260, Grade 2 Oil atomized through spark plug openings. Right Eank - VCI

plug only.

. . . .

1 of 12 cylinders remained corrosion free for three years.

6 of 12 cylinders Stage 2 corrosion spots over entire piston travel area.

3 of 12 cylinders Stage 2 corresion spots over lower half of piston travel area.

2 of 12 cylinders, Stage 3 corrosion band 1/2"-1" wide, 1800-3600 circumference of the piston travel area.

Upon reassembly and testing on a power pack test stand the following operating deficiencies were noted.

 Compression was low on all 6 cylinders of the right bank and 1 cylinder slightly low on left bank.

Stall test (Pf.:'s) read 2300 instead of the minimum 2490.
 Blow by rejectable.

All above deficiencies presumably due to faulty tiring caused by the teardown and not any deterioration and/or corrosion. Engine #8 - Same as 7.

2 of 12 cylinders remained corrosion free for three years. 2 of 12 cylinders Stage 2 & 3 corresion spots for entire piston

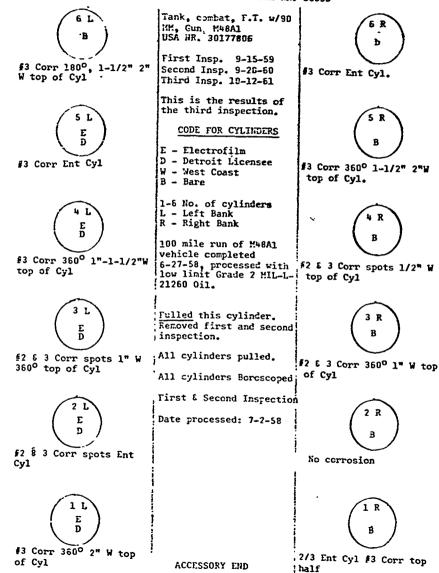
8 of 12 cylinders, Stage 2 & 3 corrosion band 1/2"-1" wide, 1800-3600 circumference of miston travel area.

4 of these same 8 showed additional strip of stage 3 corrosion 1/4" wide, 600-1800 circumference of piston travel area.

Upon reassembly and testing on a power rack test stard no operating deficiencies were noted.

ENGINE MR. 1 AVI-1790-7C SERIAL MR. 26033

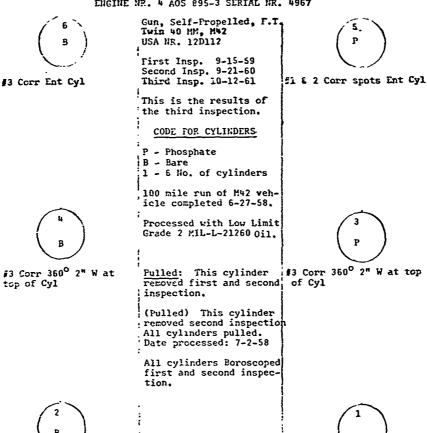
and the second s



#3 Jorr 3000 1-1/2" W

at top of Cyl

ENGINE NR. 4 AOS 895-3 SERIAL NR. 4967



ACCLSSORY END

#2 Corr spots 1-1/2" W at

top of Cyl

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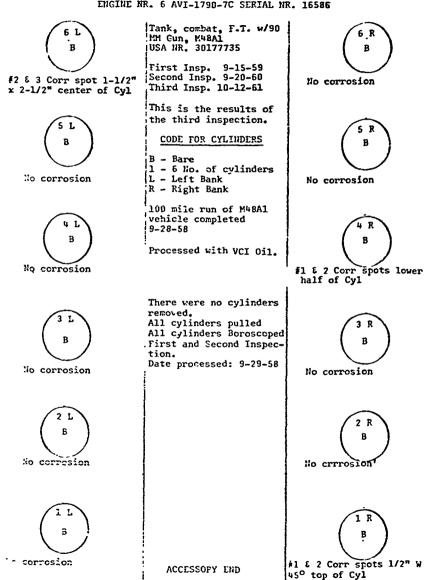
ENGINE NR. 5 AVI-1790-7C SERIAL NR. 21040 6 L Tank, combat, F.T. w/90 6 R MM Gun, M48Al В В USA NR. 30177800 First Insp. 9-15-59 Second Insp. 9-20-60 No corresion No corresion Third Insp. 10-12-61 This is the results of the third inspection. 5 R CDDE FOR CYLINDERS В B - Bare 1 - 6 No. of cylinders No corresion #1 & 2 Corr spots Ent L - Left Bank Cyl R - Right Bank 100 mile run of M48Al vehicle completed 4 L 9-28-58. В Processed with VCI Oil. #1 Corr spots Ent Cyl No corrosion Pulled: This cylinder removed first and second inspection. All cylinders pulled All cylinders Boroscoped First and Second Inspec-#2 Corr 1/8" W 180° center tion. No corrosion Date processed: 9-29-58 of Cyl 2 L В No corresion #2 & 3 Corr spots Ent Cy1 В No corrosion No corresion

ACCESSORY END

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ENGINE NR. 6 AVI-1790-7C SERIAL NR. 16586

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ENGINE NR. 7 AV-1790-B SERIAL NR. 18620

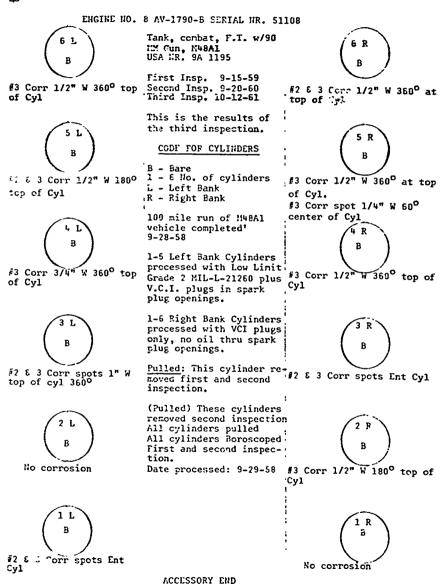
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6 R Tank, combat, F.T. w/98 MM Gun, M48AI В USA NR. 30173160 First Insp. 9-15-59 #3 Corr spots Ent Cyl Second Insp. 9-20-60 #1 & 2 Corr spots lower Third Insp. 10-12-61 half of Cyl This is the results of the third inspection. CODE FOR CYLINDERS 3 - Bare 1 - 6 No. of cylinders #2 & 3 Corr spots Ent #3 Corr 1/2" W 360° top of L - Left Bank Cyl Cy1 R - Right Bank 100 mile run of M48Al vehicle completed 9-28-59. 1-6 Left Bank Cylinders processed with Low Limit #1 & 2 Corr spots Ent Grade 2 MIL-L-21260 plus #1 & 2 Corr spots lower Cy1 V.C.I. plugs in spark half of Cyl plug openings. 1-6 Right Bank Cylinders No oil thru spark plug openings, only V.C.I. В plugs. Pulled: This cylinder reroved first and second No corresion (Pulled) These cylinders removed second inspection All cylinders pulled All cylinders Boroscoped First and Second Inspection. Late processed: 9-29-58 #3 Corr spots Ent Cyl #2 & 3 Corr 180° 1" W top of Cyl 1 R #2 & 3 Corr spots Ent #2 & 3 Corr spots lower

ACCESSORY END

half of Cyl

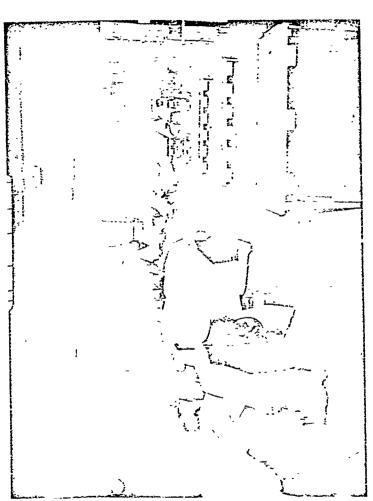
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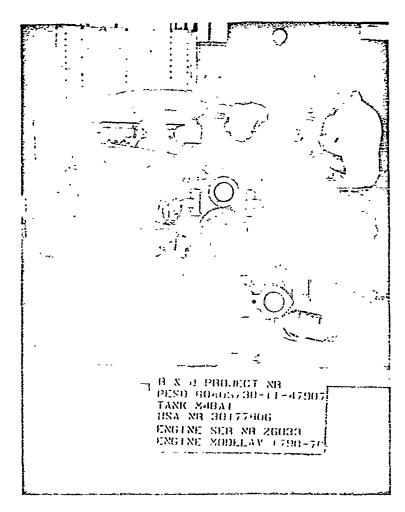
PHOTOGRAPHS

- FIGURE 1 View of outdoor storage area showing some of the combat vehicles in which test engines were installed.
- FIGURE 2 View of evaluation area where power pack assemblies (engine, transmission, fans, shroud) after disassembly from vehicles were brought in for tear-down. Engines in the rear are being disassembled with a removed cylinder assembly.shown on the table,
- FIGURE 3 View of test engine (AV 1790) from accessory or front end with fan and shrcud in background. A renoved cylinder assembly on the table. Another cylinder being boroscoped while still assembled to the engine. Boroscopes were always inserted through the spark plug openings (2 to each cylinder) for evaluation purposes of the interior cylinder area.
- FIGURE 4 View of test engine AV 1790 from accessory or front end already considerably disassembled and being further torn down for final evaluation.
- FIGURE 5 View of cylinder a sembly removed from engine looking into the interior area showing the bottom of the exhaust valve, intake valve and spark plug.

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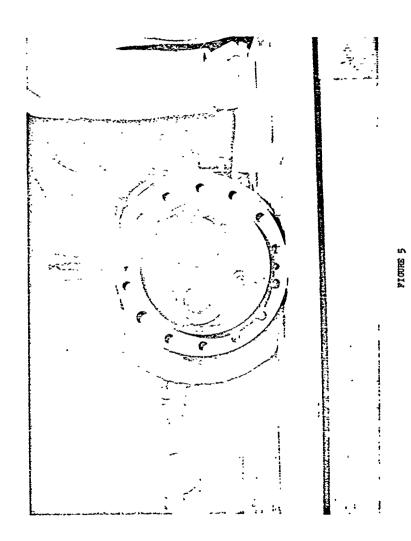
PICURE 2



PIGURE 3



PIGURE 4



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COVELLATORY NATION AND ADDRESSES ATTACK from the VCI oil of VCI COVELLATORY . There was no apparent attack from the voil of VCI COVELLATOR . There was no corrected by Linguistic features attack attack attack attack attack in a condensation is exponention of moleture. (b) Combustion product a producting an acidic anticonent.

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